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Foreign Exchange Auction Markets in Sub-Saharan Africa

Dynamic Models for Auction Exchange Rates

Janine Aron
Ibrahim Elbadawi

A strong case is made for a gradual approach to exchange-rate unification in Sub-Saharan Africa because of the huge fiscal and other macroeconomic imbalances that prevail there — and the rudimentary nature of the banking system and other economic institutions.

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Summary findings

In this analytical sequel to *A Typology of Foreign Exchange Auction Markets in Sub-Saharan Africa*, Aron and Elbadawi compare the micromanagement of different foreign exchange auctions in Sub-Saharan Africa.

Multi-unit auctions for foreign exchange were introduced in a number of countries in the 1980s and 1990s, in a transitional step toward a credible, sustainable, unified regime, such as an efficient interbank market. But there is little understanding of how auction markets function in Sub-Saharan Africa, and there has been virtually no research on the causes of frequent policy reversals or of auction failure.

One possible cause of failure — apart from thin markets, macroeconomic laxity, and vulnerability to terms-of-trade shocks and fluctuations in the disbursement of foreign aid — is the inappropriate design and management of auctions.

Aron and Elbadawi estimate models for the microdeterminants of the auction rate, using weekly data on foreign exchange auctions for Ghana, Nigeria, Uganda, and Zambia. Among the policy lessons:

- Nigeria and Zambia failed to unify and stabilize the exchange rate partly because there was no reserve price rule. When bidders learn such a rule, speculative bidding diminishes.
- The management of a credible, sustainable reserve price policy requires an efficient secondary market.

A simple underlying model, synthesized from the theoretical literature on auctions, specifies the auction rate as a function of fundamental variables and structural shift dummies. The repeated, sequential nature of these multi-unit auctions and the nonstationary nature of most of the auction variables are captured empirically by a cointegrated (error correction) framework.

In addition to consistently estimating long-run and short-run parameters of auction fundamentals, the error correction model allows asymptotically efficient testing of three policy hypotheses deriving from auction theory: the competitiveness hypothesis, the effect of uncertainty on the auction-determined rate, and the revenue-equivalence hypothesis.

In other words, they used these models to test the impact on the level of the auction rate of increased competition among bidders, of the effect of uncertainty (proxied by a volatile supply of foreign exchange), and of different pricing mechanisms (Dutch and marginal pricing).

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FOREIGN EXCHANGE AUCTION MARKETS IN SUB-SAHARAN AFRICA

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Janine Aron and Ibrahim Elbadawi

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1. INTRODUCTION

One of the most dramatic manifestations of the economic crisis that swept Sub-Saharan Africa since the second half of the 1970s, has been the emergence and the subsequent expansion of parallel markets for foreign exchange. Relative to other developing regions, the parallel premia and the size of these markets have tended to be much larger in SSA (Kiguel and O'Connell, 1992). In fact the parallel premium in most of the Sub-Saharan African countries constitutes a major economic signal reflecting policy incredibility, therefore influencing short-run as well as long-run economic decisions (e.g. Aron and Elbadawi, 1992). It is by now widely accepted that unifying the exchange rates (official and parallel) and integrating the parallel market into the regular economy should be a major policy objective for reforming African countries (e.g. Kiguel and O'Connell, 1992). Recent evidence, however, shows that achieving exchange rate unification, and more importantly sustaining it, has been a rather elusive goal.[1] The received wisdom suggests that the "best" approach to unification might be to start with nominal devaluations and gradually liberalize foreign trade transactions - the pace of reform being set by the speed and credibility of fiscal adjustment (Pinto, 1990). It is also important to emphasize that unification is a complex process that may require institutional changes as well as behavioral adjustments on the part of market participants (Agenor and Flood, 1992).

During the 1980s and 1990s, two types of flexible exchange rate regimes have been introduced in SSA, with one important goal being the sustainable unification of multiple markets for foreign exchange. These are decentralised interbank markets in foreign exchange,[2] and the innovative use of centralised foreign exchange auction markets.[3] Auctions may have advantages over moving directly to interbank markets where there is insufficient institutional depth to allow effective functioning of a decentralized foreign exchange market, where a few commercial banks have historically been dominant and there is a danger of collusion, or where there are limited sources of foreign exchange (Quirck et al, 1987, Krumm, 1985). The extent of macroeconomic imbalances (especially fiscal) that have prevailed in SSA, and the rudimentary nature of economic institutions (such as the banking system), provide a strong case for a more gradualistic approach to exchange rate unification in SSA. Where auctions have proved

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[1] The term unification in the SSA context refers to eradication of the parallel market. However, since these countries are likely to maintain capital controls in the medium term, there would remain a small role for the parallel market in meeting portfolio demand. Our concept of unification in SSA is thus a substantial reduction of the parallel market so that it is no longer a major signal in the economy.

[2] Countries which have used interbank markets include Zaire, The Gambia, Sierra Leone, Ghana, Uganda and Nigeria (in tandem with an auction).

[3] Countries which have established various types of exchange rate auctions include Bolivia (1985 onwards), Jamaica (1984-89) and African countries, Ghana (1986-92), Nigeria (1986-94), Guinea (1986-), Zambia (1985-87), Sierra Leone (1982-83), Uganda (1982-85, 1992-93) and Ethiopia (1993-).

successful in SSA, their primary role has been as a transitional medium towards a unified interbank market[4].

Two types of multi-unit foreign exchange auctions have been employed in SSA: first, retail auctions, where the bidders are private and public sector importing firms, channelling integrated price-quantity bids for foreign exchange through the non-competing banks; and secondly, wholesale auctions, where the bidders are registered banks or foreign exchange dealers. In the latter case, there may either be a free secondary (importers') market for foreign exchange, so that banks compete freely in the auction; or the banks may be restricted to submitting composite bids for foreign exchange which exactly cover importers' (and possibly their own) requirements in a strictly monitored secondary market. Two types of pricing mechanisms have been used in these auctions. These are the discriminatory or Dutch auctions, where bidders pay their own price for each unit; and competitive auctions, where bidders pay the lowest accepted bid price for each unit.

The experience with auctions in SSA has included some notable successes (e.g. auctions in Ghana and Uganda); but equally, other countries have experienced damaging speculative episodes and policy reversals (Nigeria and Zambia). The rather mixed outcome in these countries for unification and stabilisation of the exchange rate was discussed in Aron and Elbadawi (1994). The weekly evolution of the auction rates is illustrated in Figure 1. Although auctions continue to be introduced (e.g. Ethiopia in 1993), and despite the obvious policy importance. the functioning of these markets and the causes of policy reversals in SSA remains poorly understood. Apart from supply problems due to initial conditions of market thinness and vulnerability to terms of trade shocks and fluctuations in the disbursement of foreign aid, potential causes of failure include macroeconomic laxity, inappropriate auction design and poor micro-management of auctions. It is generally accepted that a successful exchange rate reform depends crucially on a stable macroeconomic environment. In the context of Sub-Saharan Africa, the decision to unify exchange rates essentially amounts to a commitment by the authorities to shift the nominal anchor from the exchange rate to the money supply. However, the micro-design features of a foreign exchange auction are more than merely a transmission mechanism for a sufficiently sustainable macro-economic environment. This is because macro-credibility does not only require consistent policy in terms of fundamentals (fiscal and monetary policy), but also depends crucially on agents' responses to their perceptions of government commitment to reform. Auction design through rules, procedures and announcements can modify and direct the bidding behaviour of participating agents.

[4] In principle, auctions with limited entry restrictions could provide a viable, long-term, market-based exchange rate arrangement. However in practice, the move to a decentralised interbank market has been favoured over retaining an auction for a number of reasons: the increased administrative requirements of a centralized auction system are costly; there is greater potential for government manipulation of the exchange rate or for rent-seeking; there is a closer association of the government to the politics of the exchange rate; and furthermore, even with few entry restrictions, the transactions costs for auction participants (particularly where donor money is being auctioned) create a wedge between the parallel and official market rates.

Unfortunately there has been virtually no empirical research in this area: part of the reason being that the analysis of sequentially repeated, multi-unit auctions presents substantial theoretical and empirical difficulties. The aim of this paper is to build on an earlier institutional and statistical paper on the SSA auctions (Aron and Elbadawi, 1994), and estimate models for the micro-determinants of the auction rate, based on a simple underlying model synthesized from auction theoretical literature, using weekly foreign exchange auction data from four Sub-Saharan African countries, Zambia, Uganda, Ghana and Nigeria. The empirical section of this paper constitutes a novel approach to empirical modelling in auction research: in the context of a dynamic model for these repeated, sequential auctions, we employ more recent econometric techniques of cointegration for efficient hypothesis testing in the presence of the regime shifts (structural breaks) which characterize these liberalization episodes in SSA.[5] We use this empirical model to evaluate some micro-economic design and management features of the foreign exchange auctions through testing policy propositions motivated by auction theory. We hope to shed some light on the causes of success and failure of the auction regimes in SSA, and provide a few policy lessons for improved design and conduct of auctions at the micro-level.

This study is partly historical, but also has substantial current relevance. Two of the countries we examined at the time of analysis had ongoing auctions (Nigeria and Uganda), auctions were introduced in Ethiopia in 1993, while more recently the question of introducing an auction to disburse foreign aid has been mooted in Zambia.[6] Secondly, there is an increasing tendency to use auctions for the market-pricing of credit and import quotas in Latin American and Eastern European countries. This trend appears to be moving to SSA, so that many of the lessons from the foreign exchange auctions, which take explicit account of the structural characteristics of these countries, will be transferable.

The structure of the paper is as follows. Section 2 discusses some analytical issues and gives an outline of a benchmark model of the auction equilibrium selling rate. Data features and the empirical methodology are presented in section 3. The model is estimated in section 4 and various hypotheses are tested to clarify policy questions, using weekly auction data from Ghana, Nigeria, Zambia and Uganda. Finally, section 5 concludes with policy lessons from SSA.

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[5] Regime shifts and unit-roots are common features of these high frequency SSA data (Aron and Elbadawi, 1994).

[6] Further, a number of Eastern European countries employ foreign exchange auctions (e.g. Romania and Khazakstan) where structural characteristics may not be too different in some cases to SSA countries.

2. THEORETICAL ISSUES

There is currently no single theoretical auction model which adequately describes the equilibrium properties of the SSA foreign exchange auctions. A composite of a number of the existing models is probably required, and most of the restrictions that are imposed in standard models have to be relaxed.

First, the foreign exchange auctions are multi-unit auctions, which differ from conventional auctions in that bidders select both the price and the quantity of units they wish to buy at that price. In contrast to single-unit auctions, the submission of integrated price-quantity bids can involve strategic behavior on the part of firms, whose payoffs may be raised by downward quantity adjustment under competitive, though not discriminative pricing (Tenorio, 1991).

Second, the auctions are not one-shot isolated events, but repeated, sequential auctions. Thus, they may embody interesting strategic dynamics and learning behavior, and many predictions from single auction models will not carry over to repeated auctions (Bikhchandani, 1988). For example, a *deception* effect may develop in sequential sales, where if the bidder knows his current bid will reveal information about later sales, he will have an incentive to underbid (Hausch, 1986). Sequential auctions may also facilitate cooperative collusive behavior amongst bidders (applying the now familiar analysis of repeated oligopoly games). The issue of commitment by the seller is important in repeated auction games (McAfee and McMillan, 1987), so that we might expect the credibility of the exchange rate liberalization to play a major role.

Third, and related to the above point, the foreign exchange auctions are not isolated events, but rather determine an integral price for the whole economy, the exchange rate. The auctions will thus also be influenced by a combination of macro-economic policies, exogenous shocks (such as TOT shocks), and political-economic features (such as treatment of the large state-owned sector).

Fourth, bidders may be risk-averse. This is because foreign exchange is a crucial input in often highly import-intensive production in SSA. Bidders face an uncertain supply of auctionable foreign exchange, due to thin markets, TOT shocks, and possibly political-economic factors; and also may be uncertain about the commitment of the seller to a market-allocation, as opposed to the prior manual allocation, of foreign exchange.

Fifth, bidders may not be symmetric in these auctions. That is, they may fall into identifiable sub-classes, so that instead of there being a single distribution from which bidders draw their valuations as is usually assumed, there may be more than one distribution. SSA importers constitute an oligopolistic set, and unquestionably some bidders are regarded as more credit-worthy. There may also be systematic production differences between multinational firms, the domestic private sector and public enterprises.

Sixth, the number of bidders may not be exogenous. The foreign exchange auctions typically involve an alteration in the rules over time (for instance, as regards transactions costs, reserve pricing rules, or information revelation), and it has been shown that different rules and formats can attract different sets of bidders (e.g. Samuelson, 1990).

Seventh, the relevant value assumptions (the determinants of bidders' payoffs) and distributional assumptions (the determinants of bidders' beliefs about their competitors) probably imply a mix of the two rather different frameworks commonly employed in auction models: the independent private values (IPV)[7] and the common values (CV)[8] models. In the retail auctions, and in those wholesale auctions where purchase of forex is tied to restricted imports and may not be sold in a secondary market, the auctioned object is in effect a proxy for an imported, intermediate input for firms. The IPV component is due to the different endowments and characteristics (see above) of the competing firms. Since these are multiple unit auctions, the diminishing marginal utility of the intermediate good suggests that additional units of forex will also have diminishing marginal utility for the firm. Further, where the exchange reform is expected to be short-lived, speculative behaviour will also depend on the privately observed opportunity cost and endowments of bidders. A CV component may be injected, for instance, when public information is used in making forecasts, resulting in value-correlations; as well as in genuine wholesale auctions (where the banks are not merely a channel for importers' bids), since the bidders' values are then linked to those in a secondary market (bureaux or interbank). Further, the repeated nature of these auctions means strategic behaviour among bidders is likely, creating an interdependence of values; while collusion, tacit or deliberate, may be facilitated.

A more general model has been developed which allows a bidder's value to depend on his tastes, those of other bidders and of non-participants, and on unobserved characteristics of the auctioned object (Milgrom and Weber, 1982). The model embodies private values and common values components, as well as a degree of interdependence (affiliation) amongst bidders' valuations. Unfortunately, most auction predictions stem from pure IPV or CV models, and are not worked out for the general model.

2.1 Towards an Empirical Model of the Clearing Auction Rate

The predictions of auction theory depend centrally on the nature of the underlying distribution of bidders' values of the auctioned object. It is clear, therefore, that a theoretically-consistent empirical

[7] The IPV model combines assumptions of private values with an independent distribution of bidders' values. Thus, bidders values of the auctioned object are treated as subjective (differences amongst bidders are due to differences in taste), and while each bidder knows his own value with certainty, he will not know the values of other bidders. The IPV model will not be applicable in auctions where there is a resale market depending on the tastes of others; nor where the object embodies certain discoverable but as yet unknown properties. The model would apply for the case of a firm bidding for inputs, where all the characteristics of the input are known. Value differences will then be due only to such factors as differences in transport costs, product mix, capacity and inventory considerations, opportunity cost and resource differences amongst the bidding firms.

[8] The CV model adopts the polar opposite of the private values hypothesis: the auctioned object has some true value which is common but unknown to all bidders. Each bidder independently estimates the true value of the auctioned object. If the bidders are treated as having symmetric information, and their estimates are unbiased, these estimates will represent independent drawings from a probability distribution with a mean equal to the true value. This model is typically applied in mineral rights auctions, where there is considerable uncertainty about the true value of the mineral, and common value elements probably dominate any private value components.

methodology that attempts to estimate structural models of auctions must involve as a first step the estimation of the values distribution. However, even for the simpler auction models, where it may prove possible to ascertain the nature of the values distribution, there are considerable difficulties in estimating structural econometric models derived from auction theory, given the extreme non-linearities and numerical complexity. Recent work employs advanced econometric methods to surmount some of the empirical problems in order to estimate structural models of auctions (e.g. Laffont et al, 1991; Laffont and Vuong, 1992; Paarsh, 1992; Gallant and Tauchen, 1992): Laffont et al (1991) use a simulation approach to derive the econometric model directly from the underlying theoretical model, first estimating the distribution of private values held by bidders. These methods are computationally feasible where the equilibrium bid has an explicit form; but it is not clear that the method can be easily generalized to more complex auction systems. Where even a few restrictions of the simple model are relaxed, the differential equations do not have a closed-form solution, and the numerical solutions prove computationally excessive. Unsurprisingly, few empirical studies have attempted to validate theoretical auction models, and most test some implications of the theory using reduced-form models. For instance, they might try to explain bids in terms of a reserve price, the number of potential bidders, characteristics of the auctioned object and characteristics of bidders which affect the common distribution of private values (e.g. Hansen, 1985; Hendricks and Porter, 1988).

Given the complex nature of the foreign exchange auctions that we examine in this paper, our research approach will be to follow the past tradition in empirical work and estimate an unrestricted reduced-form model. We then aim to test the predictions of a number of simpler auction models, to see if they apply in more general cases. In this section we posit a simple empirical model for the auction clearing rate. We account for the auction fundamentals that have effects that can be signed a priori (e.g. foreign exchange supply, the number of bidders and opportunity cost). Further, the model also allows the testing of some propositions motivated by auction theory, such as the equivalence of revenue-generation under different auction formats, the effect of uncertainty on bid levels, and the effect of increasing the pool of bidders (see section 2.2). Being a reduced-form, our model does not offer a structural interpretation of the latter effects. In section 4, where we estimate and test the model, we draw on the received wisdom from auction theory, as well as the institutional features of the auctions in question, to provide interpretation.

We begin by setting out the Harris and Raviv (1981) theory of Nash bidding behaviour, for the case where multiple units are sold in a single auction, and bidders can purchase at most one of these units. Following Vuong and Laffont (1992), we consider the type of empirical model that emerges from the solved-out equilibrium bidding strategies for both competitive and discriminatory pricing. We then consider the suitability of this empirical model for the more general case of endogenous quantity decisions by bidders (bidders can purchase more than one unit of the good) and sequentially repeated auctions.

There are Q units of a homogeneous good to be sold. The market consists of $N > Q$ bidding agents, who each compete for one unit of the good. Assume that bidding agent i, $i=1,\dots,N$ places a monetary value v_i on a unit of the good, and that each v_i is drawn with replacement from a distribution with density function h and probability function H, where the support of h is $[O, \bar{v}]$. If bidder i submits a sealed bid b_i which is accepted, then the monetary gain is $v_i - b_i$, with utility $u(v_i - b_i)$. It is assumed that $u(0) = 0$, that $u(.)$ is increasing, concave and differentiable, and that the utility of an unsuccessful bid is zero. Bids $b_i = b(v_i)$ are assumed to be symmetric Nash equilibrium strategies.[9]

These bids are arranged by the auctioneer in decreasing order of price. In the Harris and Raviv model, the Q highest bidders in a competitive auction receive one unit each at the price of the Q+1th highest bid. Harris and Raviv (1981) show that under competitive bidding, the Nash equilibrium bidding strategy for each bidder (whether risk neutral or risk averse) is to bid her true monetary value:

$$b_C(v_i) = v_i \tag{1}$$

The competitive price (clearing rate) is then $b_C(v_{N-Q}) = v_{N-Q}$.

In the discriminatory auction, the Q highest bidders pay the rate that they bid. Assume that bidder i believes his competitors will bid according to the differentiable bidding function $b_j = b(v_j)$, for $j \neq i$, where b_j is increasing on $[O, \bar{v}]$. Let π denote the inverse of b_j (i.e. $\pi(b(v_j)) = v_j$). The probability that a bid b_i will be accepted, is the same as the probability that at least N-Q of the values drawn by bidding agent i's competitors are below $\pi(b_i) = v_i$. This probability, $F(\pi(b_i))$, is given by the distribution function of the (N-Q)th order statistic for a sample of size N-1 from the distribution H:

$$F(\pi(b)) = \frac{(N-1)!}{(N-Q-1)!(Q-1)!} \int_0^{\pi(b)} [H(v)]^{N-Q-1} [1-H(v)]^{Q-1} h(v)\, dv \tag{2}$$

The ith bidding agent then has to choose b_i to maximise $u(v_i - b_i) F(\pi(b_i))$, i.e. maximise the bidder's utility should the bid be accepted, multiplied by the probability that it will be accepted. Harris and Raviv (1981) show that the Nash strategy emerging from the solution of the first order condition for this maximisation problem:

$$b_{Dn}(v_i) = \frac{1}{F(v_i)} \int_0^{v_i} x\, dF(x) \tag{3}$$

[9] The function $b(v_i)$ will be a Nash equilibrium bid function if for every i, $b(v_i)$ maximises bidder i's expected utility, given that every other bidder j uses the same strategy $b(v_j)$.

where Dn indicates risk neutrality under discriminatory pricing. Harris and Raviv also prove that where all bidders are risk averse and have the same strictly concave utility function, they will bid higher than risk neutral bidders.

We now turn to implications of these theoretical results for the specification of a reduced-form empirical model. The bid which is of special interest to us in the context of the foreign exchange auctions is the lowest accepted winning bid, which was defined to be the clearing rate in all the Dutch and competitive auctions in the four countries we consider, and the rate on which the countries' exchange rates were closely based (Aron and Elbadawi, 1994). In the foreign exchange auctions this is generally the only bid observed by the researcher, while actual private values and their distribution remain unknown. The preceding discussion showed that the solution for the bid of the N-Qth bidder under competitive or discriminatory pricing, depends on the private value of the bidder, the number of bidders, the size of supply and the distribution of private values. The same theoretical determinants will apply where the clearing rate is defined on the lowest accepted rather than the highest rejected bid. Following Laffont and Vuong (1990), we observe that since equilibrium bids are functions of private values, which are random by assumption, then observed bids for a single auction will also be random, and be uniquely determined by the above theoretical determinants. When considering several auctions in an econometric investigation, account also has to be taken of the fact that the distribution of private values may depend on the heterogeneity of the auctioned object (e.g. different characteristics of the object in different auctions that are observed by all bidders).

Based on these points, and in the auction empirical tradition, we propose a simple log-linearised, reduced-form empirical model for the clearing rate, for a series of mutually independent (no strategic behaviour), multi-unit auctions where bidders bid for at most one unit of a homogeneous good:

$$oer_t = \sum_{i=1}^{m_1} \beta_i X_{it} + \sum_{i=1}^{m_2} \delta_i DUM_i + \epsilon_t = f(F_t) + \epsilon_t \,, \tag{4}$$

where oer_t is the log of the auction clearing rate. The $X_{it} = [N, R_p, Q_s, Z]$ is a vector of variables in logs including the number of bidders (N); a reservation price (R_p), if one is used; the size of pre-announced supply (Q_s); as well as the Z variables, which are variables reflecting the observable[10] characteristics of the auctioned object, and of the buyer side of the market, which may affect the distribution of private values (Laffont et al, 1991). One important Z variable in the context of foreign exchange auctions is the secondary market (black or bureaux) exchange rate, or ber. While the resale of auctioned foreign exchange in the secondary market was largely prohibited in these auctions, in the event of the bid being unsuccessful, the bidder could resort to the more expensive secondary market. The ber

[10] The Z variables may be directly observable, or be variables over which bidders can form expectations.

reflects the opportunity cost to bidders; but is also a relevant indicator of macro-economic policy and credibility of reform (Aron and Elbadawi, 1992). The size of total demand (Q_d) is another Z variable which reflects the buyer side of the market. The dummy terms (DUM) reflect other qualitative auction fundamentals or regime shifts, such as the auction type (competitive or Dutch) or policy intervention. Note that the two auction types are not modelled separately as distinct processes, but the entire period of auctions is considered with inclusion of a dummy term to reflect the timing of the auction regime change; interactive terms between auction rate determinants and the auction dummy could also be included. Finally, ϵ_t is a stationary disturbance term.

If we allow quantity choice to be endogenous (bidders specify both the desired number of units out of Q units and the price per unit in sealed bids), the maximisation of expected utility will yield two marginal conditions, for both the price and the quantity demanded. Quantity demanded can then be solved for and substituted into the marginal price condition. While the functional form of the solution will be different to the single unit case, the determinants remain identical. Thus, the above empirical specification for oer (equation (4)), since it uses a log linear form, will also be applicable to the case of a multi-unit auction with endogenous quantity choice. The above reduced-form model also assumes a series of mutually independent auctions. The equilibrium solutions for a repeated multi-unit auction are very difficult to characterise, given the possibilities for learning by agents or strategic behaviour (e.g. Weber, 1983). We aim at least to model such dynamic behaviour empirically, by employing unrestricted dynamics in the reduced-form equation. This is discussed further in section 3.1. In the context of repeated auctions, uncertainty may be induced in bidders by a volatile supply, where supply is preannounced but only after the sealed bids have been collected. Thus a measure of the volatility of supply could be included as a Z variable (see section 2.2). The expected signs of the fundamental variables are:

$$\text{oer} = F(\underset{(+)}{N}, \underset{(-)}{Q_s}, \underset{(+)}{Q_d}, \underset{(+)}{\text{ber}}, \underset{(+)}{\text{volatility}(Q_s)})$$

2.2 Policy hypotheses motivated by auction theory.

The first policy hypothesis concerns the choice of the auction pricing mechanism. One reason given by policy-makers for their choice of a Dutch or discriminatory auction (where each bidder pays his own bid) over the competitive auction (where all bidders pay the marginal price) is the belief that Dutch pricing constitutes a disincentive to devaluation, relative to the competitive auction. That is, equilibrium price ("revenue" to the auctioneer) struck at a Dutch auction would be lower than, not equivalent to, the equilibrium price in a competitive auction.[11] There is no theoretical basis for this claim, and to date no

[11] There may be some confusion of nomenclature concerning the concept of "revenue equivalence" adopted in this paper. The term stems from auction theory and refers to the clearing price struck at a multi-unit auction for different types of auction. The policy relevance of this concept is directed at the rate of depreciation of the exchange rate, and therefore relates to the principal objective of exchange rate unification. This notion of gross revenue should be distinguished from the macro-economic

robust evidence to support it for the case of foreign exchange auctions. Since the introduction of a Dutch auction may introduce other undesirable features[12], it is important to test the veracity of the policy claim.

We will use an important result of auction theory, the revenue-equivalence theorem (Vickrey, 1961, 1962), which states that for a one-shot, single-unit auction, where bidders are risk-neutral and symmetric, and bidders' (private) valuations are uncorrelated, revenue generation is equivalent in competitive and discriminatory auctions. This prediction has proved sensitive to changes in the underlying assumptions. In the single-unit case for an IPV model, replacing the assumption of risk-neutrality with risk-aversion leads to revenue-superiority of the discriminatory auction (Harris and Raviv, 1981). Relaxing the IPV assumption by allowing risk-neutral bidders to have affiliated values, Weber (1983) shows that the competitive auction earns more revenue. However, if risk-neutral bidders in an IPV framework are not symmetric (i.e. there are observable differences amongst their valuations), the ranking is indeterminate (Maskin and Riley, 1985). If entry decisions are not exogenous, then different auction rules and formats can affect the set of bidder participants, and yield different expected revenues (e.g. Harstad et al, 1990); however, which types of auctions will revenue-dominate in the presence of multiple rule changes is not clear-cut. Finally, Robinson (1985) shows that revenue equivalence breaks down in an IPV auction under bidder collusion. In this case the Dutch auction is revenue-dominant.

The theory has focused on single-unit and one-shot IPV auctions. Engelbrecht-Wiggans (1988) extends the theory for endogenous quantity decisions, and finds revenue-equivalence for a one-shot, IPV auction where risk-neutral bidders submit full demand schedules, and each unit goes to the bidder who values it most. Taking into account that lumpy bids (several units at the same price) are in practice more usual than full demand schedules, Tenorio (1991) models endogenous quantity choice for a one-shot auction with risk neutral bidders. Revenue-superiority is indeterminate in this model.

Each of these models separately relaxes one or two assumptions of the Vickrey model, so that it is not clear which result would obtain under the relevant assumptions for foreign exchange auctions. Further, it is important to note that there is no theoretical result concerning revenue-equivalence in the repeated multi-unit case. Interpretation of our empirical results on revenue-equivalence in Dutch and competitive auctions will therefore draw on the simpler models, and consider the relative importance of the various assumptions for the countries in question.

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concept of net revenue accruing to the government as a net buyer/seller of foreign exchange (which we will examine in future work).

[12] Potential disadvantages to Dutch pricing are first, if there is a large spread between bids, this may be construed as constituting a multiple exchange rate system, with the attendant disadvantages (Quirck, 1987); and secondly, a smaller pool of bidders may ensue because the Dutch auction introduces a barrier to entry for risk-averse bidders who are poorly informed about market developments (Goldstein, 1962). Theory predicts that Dutch pricing lessens collusion (Robinson, 1985); but some authors are of the view that through a narrower range of bidders, Dutch pricing may also encourage collusion (Quirck et al, 1987).

The second policy hypothesis concerns the volatility of the number of multiple units offered for sale in sequential auctions. Policy-makers have implicated the volatility of supply in auction failure through increasing exchange rate instability. Supply to the SSA foreign exchange auctions was largely due to foreign aid and commodity export receipts. Both these components are vulnerable to shocks: aid may be suddenly withdrawn; while export concentration in primary commodities is very high in SSA, and is subject to terms of trade swings, droughts and other shocks.[13] Arguably, short-term volatility should be less important for investors than uncertainty about sustained supply in the medium-term. The perception that supply is unsustainable would damage the credibility of the exchange reform, and induce speculative activity, manifested in both price and allocation. The price is likely to overshoot a realistic rate, and the premium rise to reflect incredibility; the use of funds would be skewed towards durable goods or inventories (Calvo, 1987).[14] There may thus be important implications concerning the role of donor aid to ensure a sustainable supply in the interim.[15]

If bidders in repeated multi-unit auctions are risk averse, and are confronted with uncertainty in the form of a supply of units that may be highly volatile from week to week (where supply is pre-announced, but only after submission of all the sealed bids), theory suggests that this risk aversion will operate to the seller's advantage (Harris and Raviv, 1981). Marginally increasing the bid increases the probability of that bid being successful, even if profits are lowered for the bidder. Thus, controlling for auction type, we will test if increased supply volatility (proxying for increased uncertainty) induces a risk-premium on the bids, resulting in upward pressure on the equilibrium exchange rate.

The third and final policy hypothesis relates to competition in the foreign exchange auctions. On two of the four countries we examine the auctions were broadened over time, relaxing entry restrictions to allow more types bidders to participate, and making more items eligible for import with winning bids. In the other countries, the opposite occurred, inducing perceptions of the incredibility of the exchange rate reform, and speculative bidding. The reimposition of tighter restrictions in these countries was apparently in order to stem the more rapid increase in the auction rate (exchange rate depreciation).

We hope to test an auction-theoretic result to show that increasing the number of bidders increases the revenue on average of the seller (Harris and Raviv, 1981). Obviously the pattern of the increase will

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[13] Furthermore, supply could be well below export earnings since auctionable funds were frequently decided after satisfying the requirements of the government and public enterprises outside the auction. For instance, auctionable funds as a proportion of total inflows for Zambia and Uganda in the 1980s were estimated to be as low as 25 per cent (Quirck et al, 1987).

[14] There is evidence linking such speculative consequences with low credibility in the Zambian auction (Aron and Elbadawi, 1992; Bates and Collier, 1992).

[15] It is possible that these auctions experienced official intervention through supply manipulation to prevent exchange rate depreciation, or attain other objectives. This does not prove a problem for our estimations in section 4, because empirical models with constant parameterizations despite structural change (Table 2) exhibit super exogeneity, which implies weak exogeneity, thereby sustaining valid statistical inference (see Gilbert, 1986). However, our future research will examine more closely the potential presence of supply policy and other implicit rules.

depend on the type of auction, the characteristics of the auctioned object, and firm and industry characteristics (Brannman et al, 1987). Some auction models have clear predictions for the relationship between winning bids and the number of bidders. It may be less predictable for other types of auctions, particularly under risk-aversion, correlated values and uncertainty concerning the value of the auctioned object.

3. DATA AND EMPIRICAL METHODOLOGY.

There has been very little empirical work on foreign exchange auctions in Sub-Saharan Africa. Apart from policy-based surveys (e.g. Krumm, 1985; Quirck et al, 1987; Roberts, 1989), only the Zambian auctions appear to have been studied in any detail (e.g. Tenorio, 1993; Bates and Collier, 1993; Aron and Elbadawi, 1992). To the best of our knowledge, the only micro-economic research on the SSA auctions motivated by auction theory is due to Tenorio (1993), who tested for the revenue-equivalence of the two types of auction which appeared consecutively in the eighteen month Zambian experiment. In general, there have been no controlled experiments on foreign exchange auctions using generated data, nor have the dynamic features of repeated auctions been studied.

Yet, there is enormous scope for research on foreign exchange auctions in SSA, both in comparative time-series and cross-sectional panel data studies. The SSA case-studies present a wide spectrum of auction designs and outcomes for cross-country comparisons. In a number of countries, different auction types follow consecutively, allowing within-country comparisons of auction design. For a few countries the data set includes detailed individual bidder data for each auction; this allows an analysis of allocation, of dynamic features such as learning and strategic behavior across auctions, and the determination of the distribution of actual bidder values. Finally, weekly parallel data is available for most of the countries, so that the progress of unification can be followed throughout the transitional auction phase.

A description of our data set is contained in Aron and Elbadawi (1994). The paper discusses design characteristics for the Zambian, Ugandan, Ghanaian and Nigerian auctions, which are summarized in its Table 1. In Table 2 of that paper, basic statistics are given for the auction data, according to auction regimes, and these statistics, as well as a number of measures of non-normality of the data (skewness and kurtosis), are discussed in detail.

3.1. Cointegration Modelling in Repeated, Sequential Auctions

The analysis of the individual time series properties of the auction markets' pivotal variables, such as the level and variance of the selling price (exchange rate), the black market premium, and the demand/supply of foreign exchange, shows that the time series structures of these high frequency variables are non-stationary (i.e. with infinite variances at the limit)[16] and are dominated by structural breaks and regime shifts (see Aron and Elbadawi, 1994). This finding has important implications in its own right; for example, shocks to the auction variables tend to have high persistence. However, non-stationarity has profound effects on the econometric modelling and estimation of the behavioral theoretical specification suggested by auction theory (see section 2.1 above). When all or some of the variables involved in an econometrically estimable relationship, such as the one suggested for the auction rate, are non-stationary, it is important to guard against spurious regressions (Granger and Newbold, 1974). However, the equilibrium relationship between a number of non-stationary variables can be expressed in a stationary model if a linear combination of these variables can be found to be stationary (termed a cointegrating vector).[17] The Granger-Engle Representation theorem (Engle and Granger, 1987) states that if series are cointegrated they can be consistently represented by an error correction mechanism (ECM), which captures the short-run dynamics of adjustment towards a long-run equilibrium relationship. The attractiveness of this approach for our work is that we can model the weekly dynamics in repeated auctions with non-stationary auction variables, and follow the adjustment to unified markets in the long-run.

Therefore, to be able to ascribe any behavioural interpretations to the estimated economic relationship, it is important to test for cointegration in the regression specification, in addition to the preliminary stationarity tests on individual variables. However, a challenge is presented here in a common phenomenon in SSA countries of frequent, and often drastic, structural breaks in the series. Recent work has shown that tests that do not account for structural breaks may erroneously find non-stationarity (e.g. Perron, 1989; Hendry and Ericsson, 1993). Perron (1989) assumes the timing of the regime shifts to be known, while the others cited above offer tests of a unit root that also determine the

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[16] Formally, let $y_t = TD_t + Z_t$ be an economic series composed of a deterministic trend TD_t and a stochastic component. For simplicity assume that Z_t can be described by an autoregressive-moving average process: $A(L)Z_t = B(L)\,e_t$, where A(L) and B(L) are polynomials in the lag operator L and e_t is a sequence of i.i.d. innovations. The noise function Z_t is assumed to have mean zero, the moving average polynomial is also assumed to have roots strictly outside the unit circle. Then Z_t has a unit root if A(L) has one unit root and all other roots strictly outside the unit circle. In this case $(1-L)Z_t = \Delta Z_t$ is a stationary process and $(1-L)y_t = \Delta y_t$ is stationary around a fixed mean. If on the other hand A(L) has all its roots outside the unit circle, then Z_t is a stationary process and y_t is stationary around a trend.

[17] The idea of cointegration basically states that even though individual series may have a unit root, there may exist various linear combinations of variables which are stationary. Stated more formally in the context of the definition of the above footnote, let the n-vector y_t be composed of $(y_{it}, \dots y_{nt})$, where y_{it} is defined as in the footnote above. Then y_t is said to be cointegrated if there exists at least one n-element vector β such that $\beta' y_t$ is trend stationary. This is a milder definition of cointegration (Campbell and Perron, 1991), which is more suited to analysis of economic data since it permits the inclusion of deterministic components (such as trends and structural break dummies) in the cointegration model along with other non-stationary stochastic variables.

timing of the structural breaks. In our case, since we have precise information about the structural breaks, we opted for using Perron methodology, given its simplicity.[18]

Figure 1 shows fitted trends with one-shot intercept and/or slope changes for at least two clearly identified regimes in the auction exchange rate series for the cases of Zambia, Uganda, and Nigeria. Three distinct regimes can be identified for Ghana. The results of the tests, and the models of structural breaks corresponding to the fitted trends, are shown in Table 1, together with the critical values employed. The table reveals the presence of considerable non-stationarity and regime shifts for most of the auction data from the four countries even when structural breaks were taken into account. This is unsurprising in view of the stylised facts which emphasise rule changes, the non-normality of auction data and the importance of anticipations of policy changes.

Besides generating consistent estimates of the economic parameters implied by a model specification such as in section 2.1, the other main objective of our econometric methodology is to test some policy propositions suggested by auction theory (see section 2.2). This requires that the equilibrium model should be estimated asymptotically efficiently. Cointegration readily guarantees consistent (in fact super-consistent) estimation for the equilibrium parameters using a simple OLS regression (see Engle and Granger, 1987).[19] Unfortunately, the simple cointegration regression usually produces substantially inefficient asymptotic estimators (Phillips and Loretan, 1991). Given our interest in generating asymptotically efficient pointwise estimators with smaller margins of errors around the true equilibrium parameters, the direct cointegration estimation will not be adequate for the problem at hand. Phillips and Loretan propose a modified ECM that can be used to obtain asymptotically efficient estimation of long-run equilibria in models with stochastic trends. Subscribing to the above empirical paradigm, we will model the dynamic behavior of the auction variables with a single-equation error correction model (ECM), with leads and lags in the differences of the regressors, and which includes structural break dummy variables. This type of model will be estimated by non-linear OLS, and is recommended by Phillips and Loretan (1991) for hypothesis testing.[20] The form of the modified one-step ECM regression equation is as follows:

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[18] Perron (1989) computed critical values for a Dickey-Fuller and Augmented Dickey-Fuller tests that include two types of structural breaks: one causing a shift in the intercept, and the other a change in the slope. A key assumption of the Perron test is that these shocks are exogenous and are not a realization of the underlying data generating mechanism. Furthermore, his test requires that the timing of the shocks be known. In our case both of these two conditions apply (Aron and Elbadawi, 1994, Table 1).

[19] The justification for cointegration given the short span of high frequency (weekly) data may be somewhat problematic: ideally the requirement for non-stationarity tests to be valid is both long time series data and high frequency data. However, the span of our data is comparable with that commonly analysed in stock market and foreign exchange settings (e.g. Froot and Obstfeld, 1991 and references cited therein).

[20] Phillips and Loretan (1991) evaluate various empirical methods for estimating co-integrating relationships, and show that single equation ECM models are efficient asymptotic estimators of long-run equilibrium relationships when formulated non-linearly through the explicit inclusion of lagged equilibria, and incorporating leads and lags of differenced regressors.

$$\Delta oer_t = \sum_{i=1}^{K} \gamma_i (f(F) - oer)_{t-i} + \sum_{i=0}^{K_1} \lambda_{1_i} \Delta F_{t-i} + \sum_{i=D}^{K_2} \lambda_{2_i} \Delta F_{t+i} + \eta_t \qquad (5)$$

where, η is a stationary disturbance term, Δ is the difference operator, and f(F) is the log-linearized specification of equation (4) above, giving the determinants of the auction clearing rate.

4. ESTIMATION AND HYPOTHESIS TESTING.

This section estimates model (5) above for the micro-determinants of the auction rate. After a discussion of model diagnostics, and ascertaining that the model is broadly corroborated by data from the four countries, three hypotheses motivated by auction theory which have policy implications, will be tested. The testing will involve the revenue equivalence and competitiveness hypotheses, and also whether increased uncertainty (proxied by supply volatility) induces a risk premium on bids.

4.1 Evaluating the static and dynamic features of the estimations.

Given the characteristics of auction data (non-stationarity and regime shifts) and the repeated, sequential nature of foreign exchange auctions in SSA, we argued in section 3 on the empirical methodology for an ECM estimating framework. The ECM framework accounts for the dynamics in weekly repeated auctions, while permitting estimation of the adjustment path towards a unified equilibrium rate in the long-run. Furthermore, the expanded non-linear version of the ECM suggested by Phillips and Loretan (op. cit), which we will employ here, provides asymptotically efficient estimators for the parameters of equation (5), suitable for hypothesis testing. The empirical model is stated below. [21]

$$\begin{aligned}\Delta\log(oer)_t \quad &= \gamma_1 [\, \alpha_0 + \alpha_1 \log(Qs)_{t-1} + \alpha_2 \log(Qd)_{t-1} + \alpha_3 \log(bidt)_{t-1} + \alpha_4 \text{MAV} (\Delta\log(qs))_{t-1} \\ &\quad + \alpha_5 \log(ber)_{t-1} + \delta_0 \text{DUMDutch} + \delta_1 \text{D1} + \delta_2 \text{D2} + \delta_3 \text{D3} - \log oer_{t-1}]\end{aligned}$$

[21] For expositional purposes only, the ECM is presented in a restricted form (two error terms, one lead and two lags), but in the estimation more general lag/lead structures were considered. For a full exposition of the form and properties of the non-linear single equation ECM employed here, see Phillips and Loritan (op. cit.).

$$+ \gamma_2 [\, \alpha_0 + \alpha_1 \log(Qs)_{t-2} + \alpha_2\log(Qd)_{t-2} + \alpha_3\log(bidt)_{t-2} + \alpha_4 \, MAV\, (\Delta\log(qs))_{t-2}$$

$$+ \alpha_5\log(ber)_{t-1} + \delta_0 \, DUMDutch + \delta_1 \, D1 + \delta_2 \, D2 + \delta_3 \, D3 - \log oer_{t-2}]$$

$$+ \beta_1\Delta\log(Qs)_t + \beta_2\Delta\log(Qs)_{t-1} + \beta_3\Delta\log(Qs)_{t-2} + \beta_4\Delta\log(Qs)_{t+1}$$

$$+ \beta_5\Delta\log(Qd)_t + \beta_6\Delta\log(Qd)_{t-1} + \beta_7\Delta\log(Qd)_{t-2} + \beta_8\Delta\log(Qd)_{t+1}$$

$$+ \beta_9\Delta\log(ber)_t + \beta_{10}\Delta\log(ber)_{t-1} + \beta_{11}\Delta\log(ber)_{t-2} + \beta_{12}\Delta\log(ber)_{t+1}$$

$$+ \beta_{13}\Delta\log(bidt)_t + \beta_{14}\Delta\log(bidt)_{t-1} + \beta_{15}\Delta\log(bidt)_{t-2} + \beta_{16}\Delta\log(bidt)_{t+1} \qquad (6)$$

The variables are as defined in equation (5) above, where oer is the auction rate; Q_s and Q_d are, respectively, actual foreign exchange supplied and total foreign exchange demanded[22]; bidt is number of total bids[23]; ber is the bureaux or the parallel market exchange rate (the opportunity cost of holding foreign exhange); MAV(Δlog qs) is the moving average of the monthly variance (t_{-3}, t_{-2}, t_{-1}, t) of the rate of change in foreign exchange supply, reflecting supply variability.[24] DUMDutch is a dummy for the Dutch auction, and D1, D2 and D3 stand for regime shift dummies (defined in section 4.1). The first two bracketed terms give the first and second lagged equilibrium error (the long-run coefficients are the same). The remaining differenced lagged and lead terms represent the transitory dynamic effects on the auction rate. The equilibrium error represent the dynamic effects on the current auction rate of previous periods' departures from equilibrium. For example for a lagged positive equilibrium error (i.e a more depreciated equilibrium rate than the actual in the previous period), the fundamentals will call for an auction rate increase (depreciation) in the current period.

We employed general-to-specific modelling (e.g. see Gilbert, 1986) when estimating the non-linear empirical equation, and the results for the four countries are shown in Table 2. The results broadly corroborate the predictions of the theory, in that long-run (static) determinants of the auction rate have theoretically consistent and statistically significant effects. The data lend strong support to the ECM,

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[22] It is possible that the quantity demanded is collinear with the number of bids, and where there is learning through the use of a reserve price or pre-announced supply, also the quantity supplied. Under non-stationarity and co-integration, however, these forms of endogeneity should not constitute a problem for consistent OLS estimation of the parameters of interest, given the super-consistency of the OLS estimator (section 3.1).

[23] A positive relationship is indicated by auction theory between the number of bidders and the auction rate (Brannman et al, 1987). Given that these are integrated price and quantity bids, total demand may be a better demand indicator than the number of bids (Tenorio, 1993).

[24] Variance is not defined for non-stationary variables. Given the departure from normality (skewness and excess kurtosis) found to characterize auction data (Aron and Elbadawi (1994), skewness and excess kurtosis measures were included in our general equations, as further proxies for foreign exchange supply uncertainty (these were not found to be significant).

where the equilibrium error term in all equations is highly significant, positive and less than one. Further, the estimates also show substantial influence on the short-run evolution of the auction rate of transitory changes in auction fundamentals. Also other diagnostic indicators show that the estimated models are statistically correct (e.g. in the sense of Hendry - see Gilbert (1986)),[25] hence they can be used to test economic propositions. Before considering some theoretical hypotheses we turn to the brief description of the estimates on the effect due to the basic determinants (Qs, Qd, ber).

Table 2 contains two equations for each country. In addition to the variables estimated in equation 1, the second equation also considers foreign exchange supply variability. The coefficient of the error-correction term in the Nigeria equation is the highest at about 0.6 and is highly significant. The error-correction effects for the other three countries are also statistically significant, but their numerical values are much smaller: 0.08 for Zambia, 0.07 for Uganda and 0.02 for Ghana. This implies that adjustment towards equilibrium was relatively fast in Nigeria and rather slow for the others, especially Ghana. To eliminate 90% of an exogenous shock to the auction rate through automatic adjustment alone,[26] it takes only 4 weeks in Nigeria, compared to 26 for Zambia, 30 for Uganda and 120 for Ghana. This result agrees very closely with a Cochrane (1988) type analysis of persistence on the auction rate series (see Aron and Elbadawi, 1994). This analysis showed that the share of the random walk component in the total variance of the rate of change in the auction rate, while large for all four countries, is noticeably smaller for Nigeria, and to some extent, Zambia. The rate of convergence also started rather more rapidly in these two countries. This finding is consistent with the use of a stochastic reserve price[27] in Ghana and Uganda, as opposed to the frequent and direct policy interventions that characterized the Zambian, and especially the Nigerian auctions (Figure 1).

We now consider the parameter estimates of the long-run economic equilibrium or cointegrated relationship. Foreign exchange supply and demand are two conventional determinants of the auction rate, that are robustly estimated to have theoretically consistent signs: a sustainable increase in supply (demand) should reduce (increase) the equilibrium auction rate. The estimated coefficients are highly

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[25] Stability tests (Chow tests) found parameter stability for Zambia, Nigeria and Uganda (Table 2). The Ghana equation marginally failed the F test (at the 1 per cent level), suggesting that the relationship modelled altered over the sample period. This result was unsurprising given the length of the data series (270 auctions over six years), and reinforces the authors' opinion that the retail and wholesale auctions should be modelled separately in future research. The stability results are further reinforced by the comparative nature of the analysis, in that similar parameter estimates were obtained for the four countries. Note that parameter stability implies super exogeneity, itself implying weak exogeneity, necessary for valid statistical inference. More formally, out-of-sample forecast properties should be examined well. However, the prevalence of structural regime shifts in these high frequency data makes forecasting very problematic.

[26] The number of weeks to clear 100% of an exogenous shock through automatic adjustment alone can be computed from the formula: $(1 - \alpha) = (1 - \gamma)^T$, where γ is the coefficient of the equilibrium error term and T is the number of weeks. This formula can be obtained by manipulating the error-correction specification in (3).

[27] The reserve prices closely follow the evolution of the bureaux or parallel rates in Ghana and Uganda which are shown to be I(1) series (Table 1).

significant for the case Ghana and Uganda, but only moderately so in the other two cases (at about 10 percent significance level).[28] Another conventional effect is the opportunity cost of foreign exchange, proxied here by the bureaux (or parallel market) rate. Aside from its role as an opportunity cost, in the context of foreign exchange auctions in SSA, the black /bureaux rate is a relevant indication of macro-economic policy and credibility, and is closely linked to macro indicators such as money supply growth and inflation (Aron & Elbadawi, 1993). In all of the four countries this variable has a highly significant and positive estimated coefficient. The estimated elasticity is quite high in Ghana (0.7) and Zambia (0.76), compared to the rather moderate effects estimated for Nigeria (0.21) and Uganda (0.28). One possible explanation for this dichotomy is the degree of competitiveness in these two sets of auctions. In Ghana (for 174/270 auctions) and Zambia, the bidders are a large number of importers; while in the other two countries there are a limited number of banks bidding (even though the Ugandan auction is indirectly a retail auction). Arguably in the first case the bureaux/parallel rate is an important signal, and collusion plays no major role; hence the appreciable coefficient estimated for the black/bureaux effect.[29]

Three further potential determinants of the long-run auction rate are: auction type (Dutch pricing vs. competitive), the number of bids and foreign exchange supply variability. The effects due to these three variables provide the pretext for testing three hypotheses motivated by auction theory, with important policy implications. The Dutch auction (coefficient of DUMDutch) is found to have had significant effects in both of Nigeria and Zambia, albeit with different signs. As predicted by theory the number of bids has a positive elasticity (Nigerian equation)--confirming that increased competition leads to an auction rate depreciation. Finally supply variability was not found to be relevant to the determination of the auction rate. The interpretation of these results and discussions of the hypotheses are provided in the following sub-section.

A number of dummies relating to rules affecting bidder participation were found to be significant. For Nigeria two auction policy interventions are estimated to have effected a structural shift in the long-run auction rate. In auctions 22 and 23, after an announcement concerning tightened entry restrictions, major disqualifications of bids occurred (D2); and in auctions 60-65 various banks were barred from participating in the auctions for the same reason; also tighter ceilings on allowable foreign exchange purchases were introduced (D3). As expected the direct effects of these interventions should be to reduce competition, but perhaps more importantly the credibility of the auction regime itself may have been adversely affected as a result. Further, it is likely that adjustment had taken place already in the auction rate prior to the time the pre-announced measure was effected. Hence it is not surprising to find highly significant and positive effects for both of D2 and D3. In Zambia, auction 41 saw the institution of

[28] Given the extent of policy intervention and disqualifications in Nigeria and Zambia, it is likely that the auctions exhibit rather significant departures from the competitive model.

[29] Thus the hypothesis of homogeneity can be accepted for Ghana and Zambia (i.e. a change in the units of measurement of the exchange rate will not affect the long-run solution).

stringent documentation requirements, and heavy disqualifications occurred in that week, captured by dummy D2: the reduced demand saw a sharp fall in the auction rate. Another policy intervention causing a structural shift in the long-run rate was estimated for Uganda. Starting from auction 21, the disbursement of foreign exchange was changed to cash basis rather than a guarantee basis. This change improved the efficiency of the auction by reducing transaction costs and hence encouraged participation (by drawing agents who would otherwise may prefer to purchase foreign exchange at the more expensive but efficient bureaux de change).[30]

Finally, we briefly review the evidence on the short-run influences on the auction rate.[31] In all of the four regressions, the bureaux (parallel) rate has a significant and positive impact elasticity, in agreement with their estimated long-run effects.[32] In Nigeria, Zambia and Ghana, foreign exchange supply (and demand) have (net) negative (positive) short-run impact elasticities, again consistent with their long-run effects. In Uganda the short-run effects of these two variables are estimated significantly, but with opposite signs to their corresponding long-run elasticities. Also, surprisingly, in the Nigerian regression, an expected increase in the number of bidders ($\Delta\log(bidt)_{t+1}$) was estimated to have a negative effect on the current auction rate.

However, a possible explanation for the expected foreign exchange supply increase in Uganda, Ghana and Nigeria, and the rise in the expected number of bidders in Nigeria, and the expected foreign exchange demand in Ghana, may be due to a reverse causality between these variables and the rate of depreciation in the auction rate (left-hand side variable). Thus, current depreciation by increasing the cost of bids may have reduced the expected number of bids in Nigeria; with regard to foreign exchange supply, the authorities may be responding to current auction rate depreciation by increasing future foreign exchange supply to accommodate the liberalisation of entry restrictions; finally, decreased future demand by bidders may follow for the same reason as for the case of the number of bids.

4.2 Testing policy hypotheses.

Three policy hypotheses motivated by auction theory were introduced in section 2.2. The first policy hypothesis is the revenue equivalence hypothesis, which could be tested for Nigeria and Zambia, since competitive and Dutch auction regimes follow consecutively in each case (Figure 1). The equations are shown in Table 2, where the short-run dynamics of the repeated auctions are modelled, and perceptions of changes in reform credibility are captured by including the black market rate as regressor.

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[30] Efforts to capture the effects of progressive phases of import liberalisation and decreased entry requirements in Ghana using dummies did not prove successful, due to singularity of the data.

[31] It is important to note that the Phillips and Loritan (1991) methodology is concerned with efficient estimation and hypothesis testing in long-run economic equilibria; short-run dynamics may not be readily interpretable.

[32] Expected depreciation in the bureax (parallel) rate ($\Delta\log(ber)_{t+1}$) was estimated to have a negative impact effect of the current auction rate. The overall net short-run effect of the bureaux rate is still positive, however.

We include in f (F) in the ECM model (5) of Section 4.1, a dummy variable which captures the change in auction regime (DUMdutch is equal to 0 for the competitive auctions and to 1 for the discriminatory auctions). Referring to the empirical specification, the null hypothesis for revenue equivalence is then H_o: $\delta_o = 0$ in the long-run equilibrium term of the empirical specification (equation (6)).[33] The test compares the average level of the clearing price of a series of competitive auctions with the average clearing price of a set of discriminatory auctions. If revenue equivalence holds, the dummy variable indicating the change of regime is not expected to be significant. If the dummy is significant and positive this indicates that the Dutch auction is revenue-superior. If the dummy is significant and negative this indicates that the competitive auction is revenue-superior. We consider that this method of testing for revenue equivalence improves on an earlier analysis of this question for the foreign exchange auction in Zambia.[34]

As discussed in section 4.1, the DUMdutch dummies are significant for both Zambia[35] and Nigeria, indicating that revenue-equivalence does not obtain in these repeated, multi-unit auctions. For Nigeria, the Dutch auction is revenue-superior, while in Zambia, the competitive auction dominates. There are no theoretical results for revenue equivalence in repeated, multi-unit auctions. The important result here is that a dynamic empirical framework for repeated multi-unit auctions in two different countries found departures from revenue equivalence depending on the relevance of underlying assumptions on bidder valuations, risk-aversion and competitiveness. The theory (section 2.2) suggests that affiliation of bidders' values may explain the results in Zambia: bids were published for most of the auction, and this public information would have figured in bidders' exchange rate forecasts. For Nigeria's wholesale auction, controlling for the number of bids and rules affecting bidder participation, it appears that collusive behaviour by the small number of banks, largely state-owned, could explain the result of Dutch-dominance. High risk-aversion is not a convincing explanation for the Nigerian result, since banks were guaranteed a minimum allocation. On the strength of these two results, there appears to be no clear-

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[33] It is important to note that we are not testing for equivalence of the average change in the exchange rate across regimes: the left-hand variable in the long-run equation is the level of the equilibrium auction rate.

[34] The first-ever test of the (weak) revenue equivalence hypothesis employing actual auction data from a repeated multi-unit auction is found in Tenorio (1993). He regresses the level of the auction-determined rate in Zambia on autoregressive terms in the dependent variable, a trend term to capture any non-stationarity, controls for the supply and demand variables, and includes an auction dummy term, which equals 0 during the competitive auction and 1 for the Dutch auction. However, the dynamics in this analysis are very restrictive, including lags of the dependent variable, but without good reason excluding a priori all lagged fundamentals. The non-stationarity of the regressors was not tested for, and a general time trend was employed to capture non-stationarities. This is unnecessarily restrictive since the bubbles and expectational responses implied by normality and stationarity tests are extremely unlikely to follow an infinite linear trend. The persistence in the rate is shown by huge coefficients for the lagged rate, with all other variables insignificant, save the trend and dummies.

[35] Note that the same result (with a different magnitude of the coefficient) was achieved by Tenorio (1993) for Zambia, though in the context of poorly determined equations (see earlier footnote).

cut policy advantage in use of a Dutch auction to stem the pace of devaluation across repeated foreign exchange auctions.

Note that this test for revenue equivalence can be expressed in a stronger form, by including an interactive dummy between the number of bidders and the dummy variable for the auction method (Hansen, 1986). In this case, the null hypothesis to accept revenue equivalence implies that the coefficients on the interactive term and the separate auction format dummy term must be jointly zero. This test takes into account the fact that bidder participation may be higher under different auction formats (for instance, entry may be limited under a Dutch auction where bidding strategies are more complex - see Goldstein (1962) in the U.S.A. Treasury Bill debates). Unfortunately this test was not possible in the Zambian case due to the definition of bids.[36] For the case of Nigeria, an F test for the joint significance of the two dummy terms was $F(2,47) = 2.983$, thus still rejecting revenue equivalence (at a 10 per cent level) in favour of Dutch revenue dominance.[37]

The second policy hypothesis is concerned with the effect of increased volatility of the number of multiple units offered for sale in sequential auctions on the level of the auction rate. The hypothesis that we test, controlling for auction type, is that periods of increased supply volatility induce a risk-premium on the bids for risk averse bidders, resulting in upward pressure on the equilibrium exchange rate. This hypothesis could be tested for all four countries. The Zambian, Ghanaian and Ugandan auctions all showed a considerable degree of supply volatility (with supply not known to bidders until after the bids were submitted) for all or part of the auction regime (Aron and Elbadawi, 1994). In Nigeria, volatility was less pronounced since actual supply coincided with a fairly constant offered supply (Aron and Elbadawi, 1994: Table 1). The results are shown in Table 2. In a second equation for each country, we include in f(F) in the ECM model (5) of Section 4.1, an additional explanatory variable, the moving average of the monthly variance of the differenced supply (which is stationary). Referring to the empirical specification, the null hypothesis is then H_o: $\alpha_4 = 0$ in the long-run equilibrium term of the empirical specification (equation (6)).

For all four countries supply volatility did not prove significant. Assuming risk averse bidders, this result might be explained for the cases of Ghana and Uganda, by the use of an (unannounced) reserve pricing rule which appeared to have been learned by bidders[38]. In this case, the uncertainty induced by

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[36] In Zambia, the number of bidders does not equal the published number of bids. This is because for reasons of trade and exchange control, the published bids were dissagregated by <u>usage</u> of foreign exchange: thus each bidder's single bid was reported as components constrained to be at the same price. It is not possible to aggregate the bids and determine the number of bidders for the whole of the auction because they were only published individually for auctions 37-68. This unfortunately invalidates the attempt in Tenorio (1993) to establish "strong revenue equivalence", using an interaction dummy composed of the number of "bidders" and the regime change.

[37] The Dutch dummy becomes more positive, with somewhat reduced significance; the interactive term is insignificant.

[38] In principle, the presence of learning can be tested for (e.g. Dominguez, 1991), and this is a fruitful area for further research.

supply volatility would not induce a risk premium on the bids. Alternatively, bidders may have been risk neutral. This latter explanation probably applies for Zambia, and supports the conclusion reached on the basis of the revenue equivalence result. For Nigeria, supply was pre-announced for all or part of the auctions, in which case it was fairly stable relative to the variability of the auction rate. Preliminary regressions (not reported here) suggest that supply volatility is an important determinant of exchange rate volatility. This would be a fruitful area for further research, with the implication that foreign aid may have an important ameliorating effect on supply volatility induced by temporary terms of trade shocks.

The final testable hypothesis with policy implications concerns competitiveness in auctions. We consider the following hypothesis: the level of the exchange rate rises with expansion of the auction through expanding the number of eligible bidders/items. We test this hypothesis by including the number of bids in f (F) in the ECM model (5) of Section 4.1. The null hypothesis is H_0: $\alpha_3 = 0$ in the empirical specification of the long-run equilibrium term (equation (6)).[39] Unfortunately we were only able to test this hypothesis for Nigeria. The reason is that in Ghana, total bid data is only available for the retail auction; in Uganda, bid data refers to aggregated bids submitted by banks; in Zambia, total bids include multiple bids at the same price by individual importers, differentiated by the use of foreign exchange. The results for Nigeria show a significant and positive effect for the number of bids, showing that in the long-run there is evidence for the theoretically-predicted competitiveness effect in a multi-unit repeated auction. It is important to note that this result obtains with the model controlling for policy interventions and the consequent structural shifts which characterised the Nigerian auction.

5. CONCLUSIONS.

This paper has estimated models for the micro-determinants of the auction rate using weekly foreign exchange auction data from four Sub-Saharan African countries, Zambia, Uganda, Ghana and Nigeria. A simple underlying model synthesized from auction theoretical literature specifies the auction rate as a linear logarithmic function of fundamental variables and structural shift dummies. It was not possible to produce a structural model, as currently there is no available theoretical model in the literature for repeated sequential multi-unit auctions of this type. However, the repeated, sequential nature of these auctions and the non-stationarity of most of the individual auction variables was captured empirically by a cointegrated (error correction) framework. Even though this model does not allow a structural interpretation of the auction rate determinants, it permits estimation of the long-run path of the auction

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[39] Cointegration has one distinct advantage when measuring the effect of competition on bid levels. Hansen (1985) points out that with a positive reserve price, the theoretically relevant variable for the number of bidders is not the actual number of bidders, but the unmeasurable potential number of bidders. Giley and Karels (1981) have corrected for this truncated error problem by the Heckman procedure, including a dichotomous bidding decision: bid/do not bid. However, in the context of cointegration, the variables involved are I(1), and the estimators will be consistent whether or not the bidding decision dummy variable is included.

rate in addition to accounting for short-run dynamic behaviour. In addition to consistently estimating long-run and parameters of auction fundamentals, a modified version of the error correction model (a la Phillips and Loritan, 1991) allows asymptotically efficient testing of three policy hypotheses motivated by auction theory. These are the revenue equivalence hypothesis, the competitiveness hypothesis and the effect of uncertainty on the auction-determined rate.

5.1 Summary of results.

The variables for which theoretically predicted effects could be assigned a priori are foreign exchange supply, demand, and the opportunity cost (parallel or bureaux exchange rate). The empirical results strongly corroborate the theoretical predictions in that sustained increased foreign exchange supply (demand) leads to an equilibrium auction rate appreciation (depreciation). Also, the parallel/bureaux rate was positive and strongly significant, representing an opportunity cost to bidders, but also signalling incredibility of macro-economic policy (see also Aron and Elbadawi, 1994). The model also lends strong support to the error correction framework, where the current auction rate is shown to adjust to previous departures from equilibrium, while transitory movements in the fundamentals influenced the auction rate in the short-run. Finally, dummy variables representing policy interventions in Nigeria, Uganda and Zambia were found to effect structural shifts in the long-run auction rate.

The revenue equivalence hypothesis was tested for Nigeria and Zambia, where episodes of competitive and Dutch auctions followed consecutively. In both cases evidence was found against the revenue-equivalence hypothesis, with the Dutch auction (strongly) revenue-superior in Nigeria, and the competitive auction (weakly) dominating in Zambia. The interpretation of this result, however, is not straightforward, given that there is no theoretical result for repeated, multi-unit auctions. Theoretical models for more restricted auctions suggest several reasons for the result of non-equivalence (section 2.2). A possible explanation for revenue-superiority of the competitive auction is that bidders' private values are correlated, with risk-neutral and symmetric bidders (Weber, 1983). This result seems plausible for Zambia, given that the bids were published weekly for most of the auctions. A feasible explanation for Dutch-dominance in the wholesale auction in Nigeria is collusive behaviour by a small number of predominantly state-owned and risk-neutral banks (Robinson, 1985). To the extent that these results are robust, this implies that no revenue advantage can be assigned a priori to a repeated, multi-unit auction, irrespective of the underlying valuation characteristics of bidders. Apart from the static analysis of Tenorio (1993), this hypothesis has not been tested for repeated multi-unit auctions using actual auction data.

The impact of supply volatility (a proxy for uncertainty) on the level of the auction rate in repeated auctions was tested for all four countries, controlling for auction type, but was not found to produce a risk-premium on the auction-determined rate in any country. In Ghana and Uganda, the use of a reserve price served to stem downward volatility in thin markets, or where disqualification for failing to abide by documentation requirements reduced demand. Moreover, although the rule was not pre-announced, it was fairly transparent to bidders, so that despite the higher supply volatility in Ghana and Uganda relative to the other two countries, the exchange rate prescribed a fairly stable path. An alternative explanation is that bidders were risk neutral in these auctions. This result may apply for Zambia (where no binding reserve price was used), and accords with the conclusions above on revenue equivalence. On the contrary, for Nigeria, supply volatility was too limited to have the expected effect because foreign exchange supply was used as target variable to stabilise the exchange rate (without success). However, these results should not be taken to imply that supply volatility did not matter in these auctions: in preliminary regressions (not reported here) we found supply volatility to be an important determinant of exchange rate volatility. This would be a useful area for further research, with the implication that foreign aid may ameliorate supply volatility induced by temporary terms of trade shocks.

The role of competitiveness effects in auctions could only be tested for Nigeria. Our results show that controlling for policy intervention and consequent structural shifts which characterised the Nigerian auction, an increased number of bidders lead to equilibrium auction rate depreciation in repeated, multi-unit auctions. This prediction from auction theory for more restricted auctions, has been found to hold in other types of one-shot, multi-unit auctions (McAffee and McMillan, 1987). However, this is the first corroboration of the theory for a repeated, multi-unit auction.

5.2 Policy lessons.

In broad summary, these empirical results corroborate the distinction between two sets of countries in terms of design features, auction policies and outcomes.[40] Ghana and Uganda represent a set where auctions have been largely on target in terms of the three policy objectives of exchange rate unification, stabilisation of the exchange rate and an efficient allocation of foreign exchange. On the other hand, the auctions in Zambia and Nigeria were subject to frequent policy interventions, with the consequence of unsustainable auctions, inefficient allocation through ad hoc disqualifications (at least in Zambia), limited unification, and a rather volatile exchange rate. A number of policy lessons for exchange rate reform in SSA can be distilled from these results.

First, in large measure, the failure to achieve exchange rate unification and a stable exchange rate in Zambia and Nigeria can be attributed to the absence of a reserve price rule. Our results suggest that use of a fairly predictable reserve price stabilises foreign exchange auctions, given the limited depth of SSA financial markets. The rule is learned by bidders, and diminishes speculative bidding.[41]

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[40] Furthermore, the distributional analysis in a companion paper (Aron and Elbadawi, 1994) also produced a clear distinction between the two sets of countries. For example, the distribution of the auction rate exhibits left skewness (tendency towards appreciation) in Nigeria and Zambia; while the opposite was observed for Ghana and Uganda.

[41] In principle, a pre-announced and stable supply policy rule could achieve a similar stabilising effect. However, we have shown that in practice the endemic potential variability of foreign exchange earnings (excluding aid) in SSA, makes it difficult for an auctioneer to guarantee credibly a stable supply in the medium-run. Furthermore, a supply rule does not achieve the close

Second, the management of a sustainable and credible reserve price policy requires an efficient secondary market. The use of legalised bureaux markets in Uganda and Ghana had two advantages in this respect: they are likely to be deeper markets, and moreover eliminate the risk-premium associated with illegality. Macro-economic policy remains crucial to the success of the reserve pricing policy (Aron and Elbadawi, 1994). A stable and consistent macro-economic environment, permitted the development of a stable and steadily depreciating bureaux rate in Ghana and Uganda, while the highly volatile illegal parallel rate was not suitable as a guide for policy in Zambia and Nigeria.

Third, auction rate depreciation as a consequence of increased liberalisation and hence competition in the auctions, is consistent with fundamental market behaviour, and as such stabilises the auction and fosters long-term unification. This has been the experience of Ghana and Uganda. In contrast Nigeria and Zambia attempted to stem depreciation through increased entry restrictions (and ad hoc disqualifications) over time: these policies back-fired and merely increased damaging speculative behaviour. Given the initial conditions of thin and rather rudimentary financial markets in SSA, there may be advantages from a more gradual liberalization for allowing institution-building and learning by agents in the market - bidders, bureaux, commercial banks, and the auction managers (Aron and Elbadawi, 1994). Gradualism may also be justified from a macro-perspective, given the substantial macro-imbalances and the low credibility that often characterise initial conditions in reforming SSA countries.

Fourth, choosing Dutch over competitive pricing does not provide an automatic revenue advantage, though it may where there are a small number of bidders engaging in strategic behaviour, or where risk-aversion is paramount. However, the Dutch auction may introduce other undesirable features such as a reduced pool of bidders and inefficiences associated with a multiple rate system.

Fifth, while supply volatility - with supply announced only just before opening the sealed bids - does not produce a risk-premium on the level of the auction rate, there is preliminary evidence that it is important for auction rate volatility. This finding bears further investigation, with the potential implication that stability of foreign aid could play an important role in compensating for fluctuations in export earnings induced by trade shocks and/or natural disasters.

Sixth, although we did not specifically address the issue of allocation in the auctions, anecdotal evidence suggests that efficiency of allocation improved relative to the previous system of manual allocation under a fixed rate. However, it is to be expected that ad hoc disqualifications as occurred in Zambia diminished these advantages.

Finally, the evidence from Ghana and Uganda as against Nigeria and Zambia, suggests the paramount importance of transparent policy rules and conduct of the auctions. Lack of transparency is tantamount to unnecessary increased discretion by the auction managers, thus exacerbating one of the major potential weaknesses of the auction regime.

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linkage with macro-policy evolution and external shocks that is immediately reflected in a reserve price based on a secondary free market.

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TABLE 1: **Tests for unit roots with structural breaks.**

ZAMBIA model: $y_t = c + t + y_{t-1} + \sum_{i=1,k} \Delta y_{t-i} + DU + DT$

	log(var) + dummies		Δlog(var) + dummies		Δlog(var) - dummies	Order of I
	DF	ADF(k=4)	DF	ADF(k=4)	ADF(k=4)	
log(oer)	-3.81	-3.29	-9.49	-3.84	-3.79	I(1)
log(max)	-5.21	-3.66	-6.51	-4.07	-4.10	I(1)
log(min)	-5.28	-3.64	-13.73	-4.31	-4.21	I(1)
log(max-min)	-4.40	-4.12	-12.83	-5.29	-5.26	I(0)
log(Qs)	-6.55	-3.40	-10.21	-5.82	-5.28	I(1)
log(Qd)	-4.27	-3.78	-9.83	-3.65	-3.69	I(1)
log(Qs/Qd)	-5.31	-2.65	-10.51	-4.93	-4.85	I(1)
log(bidt)	-3.52	-3.02	-9.02	-3.84	-3.46	I(1)
log(bids/bidt)	-4.46	-2.78	-8.57	-4.75	-4.66	I(1)
log(prem)	-3.31	-2.82	-8.11	-3.94	-3.86	I(1)

1. Critical values with dummies (Perron, 1989): breakpoint in sample: $\alpha=0.6$; large sample; significance level: $t_\alpha=4.24$ (5%), $t_\alpha=3.95$ (10%).
2. Critical values without dummies (Banerjee et al, 1992): 100 observations; significance level: $t_\alpha=4.04$ (1%), $t_\alpha=3.45$ (5%).
3. Trend dummies for breakpoint T_B: t=trend; $DU_t=1$ if $t>T_B$, and 0 otherwise; $DT_t=t$ if $t>T_B$, and 0 otherwise.

UGANDA model: $y_t = c + t + y_{t-1} + \sum_{i=1,k} \Delta y_{t-i} + DU + DT$

	log(var) + dummies		Δlog(var) + dummies		Δlog(var) - dummies	Order of I
	DF	ADF(k=4)	DF	ADF(k=4)	ADF(k=4)	
log(oer)	-7.79	-2.97	-4.67	-5.33	-4.72	I(1)
log(max)	-7.99	-4.68	-12.39	-6.33	-6.34	I(0)
log(min)	-6.70	-7.55	-27.93	-7.70	-7.90	I(0)
log(max-min)	-8.89	-4.32	-12.34	-6.36	-6.47	I(0)
log(Qs)	-8.55	-3.58	-15.64	-5.29	-5.34	I(1)
log(Qd)	-7.72	-4.64	-12.74	-6.13	-6.31	I(0)
log(Qs/Qd)	-7.24	-4.68	-13.86	-5.20	-5.49	I(0)
log(bidt)	-7.34	-2.78	-15.33	-5.20	-5.26	I(1)
log(bids/bidt)	-7.63	-4.68	-13.86	-5.20	-5.47	I(0)
log(ber)	-0.92	-2.88	-4.80	-4.81	-3.26	I(1)
log(prem)	-2.29	-2.65	-5.24	-4.02	-2.78	I(1)

1. Critical values with dummies (Perron, 1989): breakpoint in sample: $\alpha=0.3$; large sample; significance level: $t_\alpha=4.17$ (5%), $t_\alpha=3.87$ (10%).
2. Critical values without dummies (Banerjee et al, 1992): 100 observations; significance level: $t_\alpha=4.04$ (1%), $t_\alpha=3.45$ (5%).
3. Trend dummies for breakpoint T_B: t=trend; $DU_t=1$ if $t>T_B$, and 0 otherwise; $DT_t=t$ if $t>T_B$, and 0 otherwise.

TABLE 1: (Contd.)

<u>GHANA</u> model: $y_t = c + t + y_{t-1} + \sum_{i=1,k} \Delta y_{t-i} + DU_t + DT^*_t$

	log(var) + dummies		Δlog(var) + dummies		Δlog(var) - dummies	Order of I
	DF	ADF(k=4)	DF	ADF(k=4)	ADF(k=4)	
log(oer)	-3.74	-3.74	-14.14	-6.38	-6.41	I(1)
log(max)	-3.48	-4.77	-15.00	-7.14	-7.15	I(0)
log(min)	-9.70	-3.57	-14.70	-6.48	-6.49	I(0)
log(max-min)	-5.44	-2.44	-22.09	-6.61	-6.52	I(0)
log(Qs)	-11.79	-4.68	-22.86	-11.72	-11.69	I(0)
log(Qd)	-8.92	-6.01	-19.67	-9.08	-9.11	I(0)
log(Qs/Qd)	-9.41	-7.07	-20.02	-9.97	-9.96	I(0)
log(bidt)	-6.16	-4.01	-16.82	-7.68	-7.68	I(1)
log(bids/bidt)	-7.08	-5.86	-16.10	-7.89	-7.89	I(0)
log(ber)	0.35	-0.24	-10.13	-6.55	-5.98	I(1)
log(prem)	-0.48	-0.48	-10.51	-6.93	-6.42	I(0)

1. Critical values with dummies (Perron, 1989): breakpoint 1 in sample: $\alpha=0.4$; breakpoint 2 in sample: $\alpha=0.7$. Using $\alpha=0.7$; large sample; significance level: $t_\alpha=3.80$ (5%), $t_\alpha=3.51$ (10%).
2. Critical values without dummies (Banerjee et al, 1992): >100 observations: significance level: $t_\alpha=3.96$, (1%), $t_\alpha=3.41$ (5%).
3. Trend dummies for breakpoints T_B: t=trend; $DU_t=1$ if $t>T_B$, and 0 otherwise; $DT^*_t=t-T_B$ if $t>T_B$, and 0 otherwise.
4. Sample sizes for number of bids and bureaux data are less than 270 (Aron and Elbadawi, 1994: Table 2). In the former case no dummies are used in the tests.

<u>NIGERIA</u> model: $y_t = c + t + y_{t-1} + \sum_{i=1,k} \Delta y_{t-i} + DU + DT$

	log(var) + dummies		Δlog(var) + dummies		Δlog(var) - dummies	Order of I
	DF	ADF(k=4)	DF	ADF(k=4)	ADF(k=4)	
log(oer)	-5.01	-2.90	-13.86	-4.88	-4.11	I(1)
log(max)	-1.82	-2.88	-7.28	-4.16	-3.74	I(1)
log(min)	-5.19	-3.49	-10.11	-5.44	-5.60	I(1)
log(max-min)	-4.52	-3.63	-9.87	-4.70	-4.72	I(1)
log(Qs)	-5.73	-4.17	-9.49	-6.16	-4.81	I(0)
log(Qd)	-5.60	-3.94	-9.97	-5.39	-4.42	I(0)
log(Qs/Qd)	-5.31	-4.39	-10.51	-4.29	-4.35	I(0)
log(bidt)	-5.60	-3.96	-8.70	-5.93	-5.67	I(0)
log(bids/bidt)	-5.71	-4.73	-13.41	-4.58	-4.89	I(0)
log(ber)	-3.53	-2.62	-9.59	-4.36	-4.30	I(1)
log(prem)	-5.30	-3.71	-12.52	-4.00	-3.58	I(1)

1. Critical values with dummies (Perron, 1989): breakpoint in sample: $\alpha=0.4$; large sample; significance level: $t_\alpha=4.22$ (5%), $t_\alpha=3.95$ (10%).
2. Critical values without dummies (Banerjee et al, 1992): 100 observations; significance level: $t_\alpha=4.04$ (1%), $t_\alpha=3.45$ (5%).
3. Trend dummies for breakpoint T_B: t=trend; $DU_t=1$ if $t>T_B$, and 0 otherwise; $DT_t=t$ if $t>T_B$, and 0 otherwise.
4. Note that the fitted trend shown in Figure 1d could not be used in these tests, due to singularity of the data: the regime change from auction 2-3 is thus not included here.

TABLE 2: Estimation of the equilibrium auction rate for Zambia, Uganda, Ghana and Nigeria.

	ZAMBIA	
	Equation 1	Equation 2
static:		
equilibrium error	0.83976E-01 (2.1724)	0.95212E-01 (2.2383)
constant	0.28815 (0.34028)	022150 (0.29471)
$\log(Qs)_{t-1}$	-0.79092 (-1.7707)	-0.68865 (-1.7875)
$\log(Qd)_{t-1}$	0.65355 (1.8635)	0.62815 (2.0686)
$\log(BER)_{t-1}$	0.76105 (2.7533)	0.74578 (3.0148)
MAV $(\Delta\log(qs))_{t-1}$	... ...	0.18622 (0.70249)
DUMDutch	-0.55716 (-1.9242)	-0.48879 (-1.9254)
D2	-2.5048 (-1.8842)	-2.2399 (-0.19679)
dynamic:		
$\Delta\log(Qs)_t$	-0.47414E-01 (-3.7027)	-0.46943E-01 (-3.6400)
$\Delta\log(Qd)_t$	0.31940E-01 (2.0072)	0.34691E-01 (2.0954)
$\Delta\log(ber)_t$	0.60805 (10.451)	0.61353 (10.379)
$\Delta\log(ber)_{t-1}$	-0.10353 (-2.3071)	-0.96324E-01 (-2.0723)

diagnostics:

(t-statistics in parentheses)		
log of likelihood function =	142.331	142.587
no. of observations =	64	64
SE regression =	0.28766E-01	0.289250E-01
R-squared =	0.754487	0.921638
adjusted R-squared =	0.906852	0.905819
DW statistic =	1.2347	1.2299
sum of squared residuals =	0.438557E-01	0.435067E-01
ADF(4) residual =	-4.94	-4.99
CHOW F(9,44) =	1.278191	

TABLE 2: (Contd.)

	NIGERIA	
	Equation 1	Equation 2
static:		
equilibrium error	0.65960	0.65928
	(6.4366)	(6.3630)
constant	0.26381	0.25274
	(0.80320)	(0.71291)
$\log(Qs)_{t-1}$	-0.17620	-0.17566
	(-1.6060)	(-1.5815)
$\log(Qd)_{t-1}$	0.19982	0.20074
	(1.7649)	(1.7467)
$\log(BER)_{t-1}$	0.20691	0.15219
	(2.2967)	(1.5929)
$\log(bidt)_{t-1}$	0.15225	0.20950
	(1.6110)	(2.1925)
MAV $(\Delta\log(qs))_{t-1}$	...	0.30276E-01
	...	(0.89207E-01)
DUMDutch	0.73946E-01	0.73533E-01
	(1.9860)	(1.9390)
D2	0.11321	0.11277
	(2.7757)	(2.7158)
D3	0.24356	0.24218
	(4.2873)	(4.0746)
dynamic:		
$\Delta\log(Qs)_t$	-0.31201	-0.31179
	(-4.751)	(-4.0279)
$\Delta\log(Qs)_{t-2}$	-0.78437E-01	-0.78090E-01
	(-1.8868)	(-1.8510)
$\Delta\log(Qs)_{t+1}$	0.21655	0.21643
	(5.0387)	(4.9813)
$\Delta\log(Qd)_t$	0.24647	0.24695
	(4.2691)	(4.2151)
$\Delta\log(ber)_{t-2}$	0.36113	0.35918
	(2.2747)	(2.2186)
$\Delta\log(bidt)_{t-1}$	-0.11894	-0.11698
	(-2.3799)	(-2.1229)

diagnostics: (t-statistics in parentheses)

log of likelihood function =	124.551	124.556
no. of observations =	63	63
SE regression =	0.38389E-01	0.387926E-01
R-squared =	0.754487	0.754529
adjusted R-squared =	0.682879	0.676187
DW statistic =	2.0934	2.1039
sum of squared residuals =	0.707408E-01	0.707289E-01
ADF(4) residual =	-4.47	-4.45
CHOW F(13,35) =	1.513739	

TABLE 2: (Contd.)

	GHANA Equation 1	GHANA Equation 2
static:		
equilibrium error	0.18738E-01	0.18867E-01
	(4.3744)	(4.3329)
constant	0.18048	0.11443
	(0.24403)	(0.15580)
$\log(Qs)_{t-1}$	-0.31869	-0.30229
	(-2.4983)	(-2.4001)
$\log(Qd)_{t-1}$	0.86500	0.86011
	(4.2207)	(4.1771)
$\log(BER)_{t-1}$	0.77307	0.77751
	(4.8948)	(4.9073)
MAV $(\Delta\log(qs))_{t-1}$	...	0.91567E-01
	...	(0.77940)
dynamic:		
$\Delta\log(Qs)_t$	-0.89511E-02	-0.87323E-02
	(-4.5084)	(-4.3784)
$\Delta\log(Qs)_{t-2}$	-0.41345E-02	-0.41627E-02
	(-2.4253)	(-2.4457)
$\Delta\log(Qs)_{t-1}$	0.54115E-02	0.55080E-02
	(3.2045)	(3.2647)
$\Delta\log(Qd)_t$	0.17074E-01	0.17048E-01
	(8.9847)	(8.9486)
$\Delta\log(Qd)_{t-1}$	-0.38971E-02	-0.40007E-02
	(-2.6323)	(-2.6871)
$\Delta\log(Qd)_{t-2}$	0.35241E-02	0.35106E-02
	(2.1075)	(2.0984)
$\Delta\log(Qd)_{t-1}$	-0.45130E-02	-0.43208E-02
	(-2.6181)	(-2.4807)
$\Delta\log(ber)_t$	...	0.40908E-01
	...	(1.5777)
$\Delta\log(ber)_{t-2}$	0.63480E-01	0.65041E-01
	(2.4916)	(2.5533)

diagnostics:

(t-statistics in parentheses)		
log of likelihood function =	970.719	972.235
no. of observations =	266	266
SE regression =	0.645304E-02	0.644188E-02
R-squared =	0.459540	0.465665
adjusted R-squared =	0.433905	0.435862
DW statistic =	1.9582	1.9525
sum of squared residuals =	0.105354E-01	0.104160E-01
ADF(4) residual =	-6.25	-6.30
CHOW F(13,240) =	2.586580	

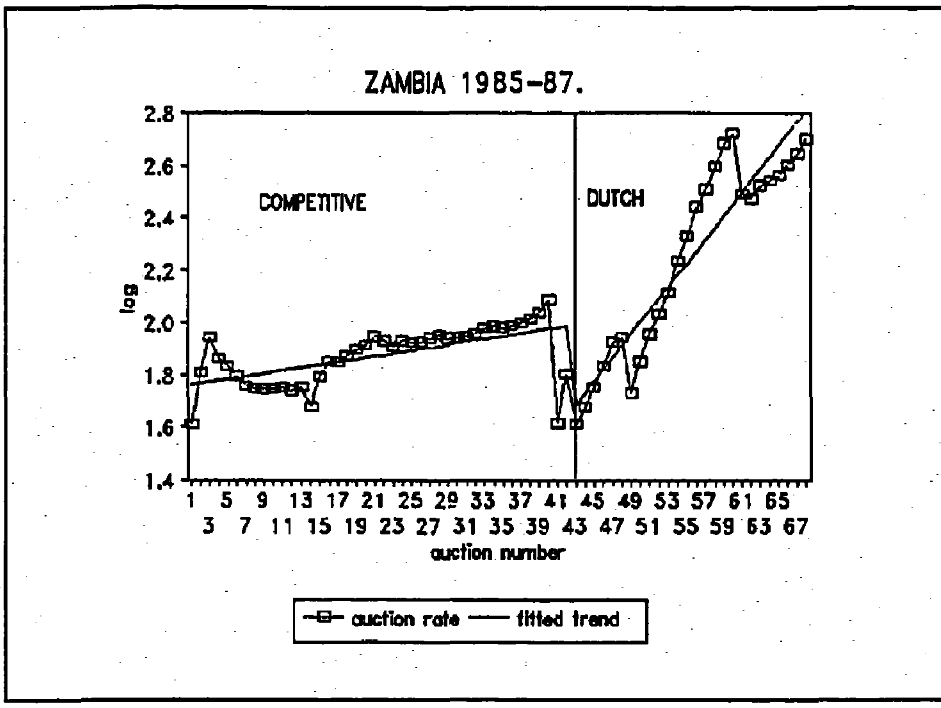
TABLE 2: (Contd.)

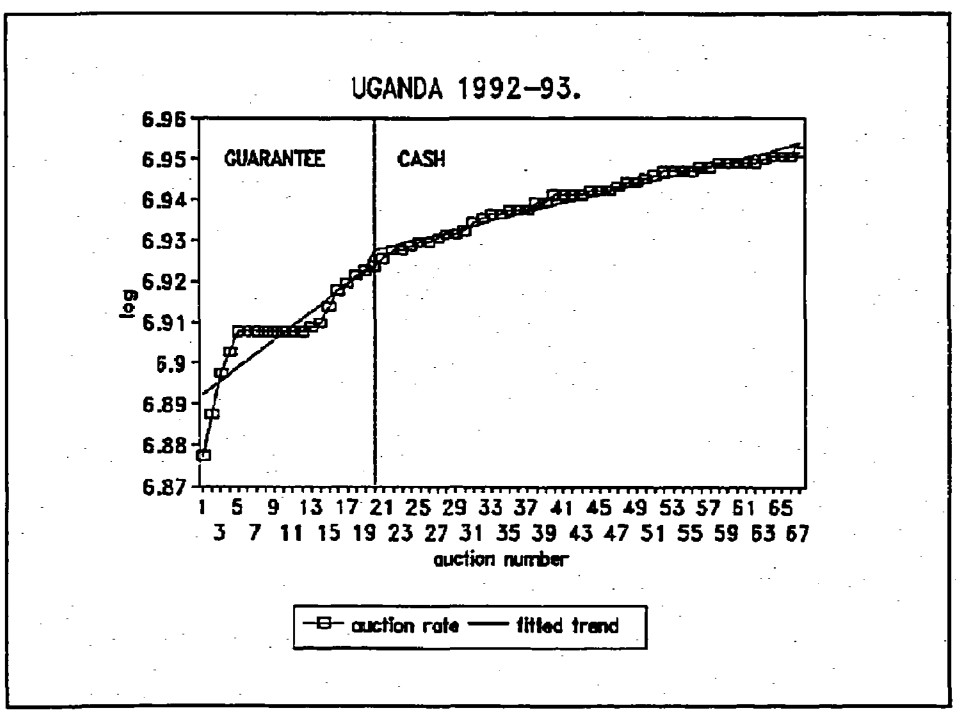
	UGANDA	
	Equation 1	Equation 2
static:		
equilibrium error	0.74353E-01	0.75010E-01
	(4.4143)	(4.4142)
constant	4.9556	4.9849
	(5.8287)	(5.8731)
$\log(Qs)_{t-1}$	-0.29395E-01	-0.28255E-01
	(-2.9863)	(-2.8708)
$\log(Qd)_{t-1}$	0.44106E-01	0.42668E-01
	(3.6213)	(3.5095)
$\log(BER)_{t-1}$	0.27697	0.27292
	(2.3066)	(2.2770)
MAV $(\Delta\log(qs))_{t-1}$	...	-0.38358E-05
	...	(-0.61284)
DUMguarantee	0.11474E-01	0.11360E-01
	(1.9859)	(1.9633)
dynamic:		
$\Delta\log(Qs)_{t-1}$	0.93263E-03	0.90164E-03
	(2.2358)	(2.1315)
$\Delta\log(Qs)_{t+1}$	0.59881E-03	0.56979E-03
	(3.2272)	(2.9566)
$\Delta\log(Qd)_t$	0.95845E-03	0.95213E-03
	(2.9789)	(2.9376)
$\Delta\log(Qd)_{t-1}$	-0.11460E-02	-0.11068E-02
	(-2.3998)	(-2.2818)
$\Delta\log(ber)_t$	0.85835E-01	0.12322
	(2.1438)	(3.0896)
$\Delta\log(ber)_{t-2}$	0.12043	0.92119E-01
	(3.0604)	(2.2147)

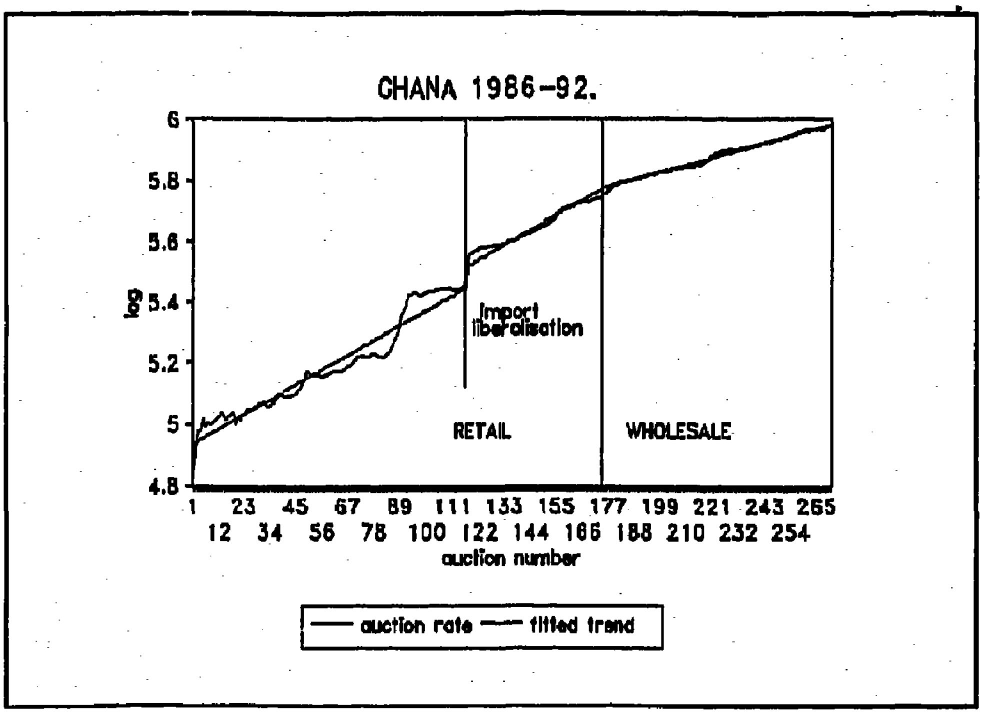
diagnostics:

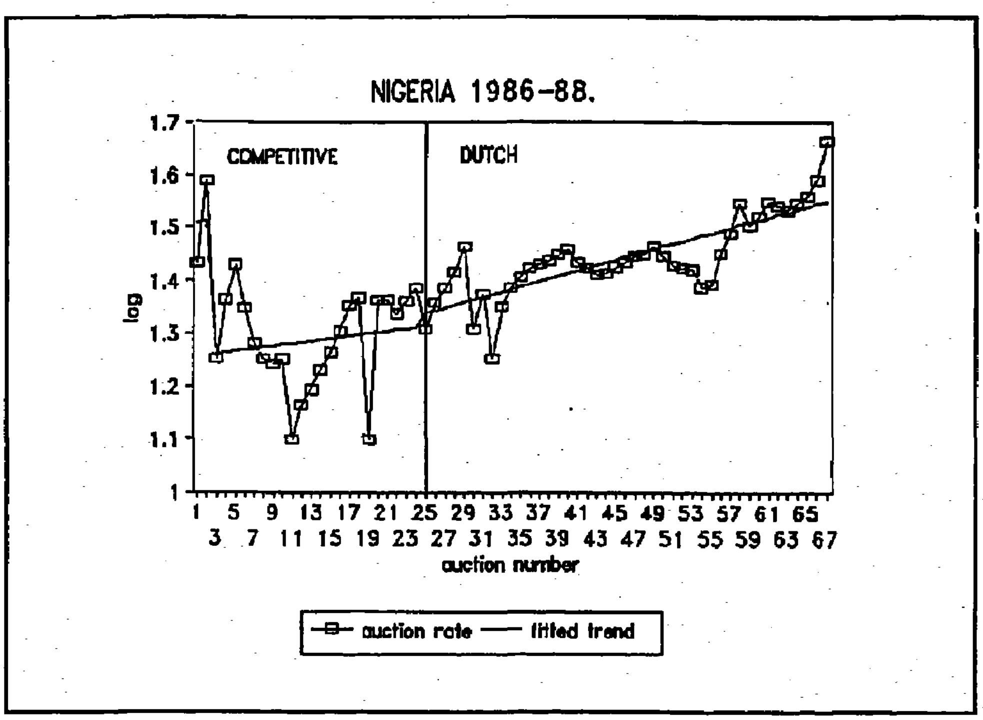
(t-statistics in parenthesis)		
log of likelihood function =	337.319	337.560
no. of observations =	58	58
SE regression =	0.809678E-03	0.815224E-03
R-squared =	0.635630	0.638651
adjusted R-squared =	0.548498	0.542291
DW statistic =	1.8440	1.8867
sum of squared residuals =	0.301566E-04	0.299066E-04
ADF(4) residual =	-3.54	-3.59
CHOW F(11,35) =	1.098098	

FIGURE 1 a,b,c,d: **Regime shifts and the equilibrium auction price in the SSA auctions.**






GHANA 1986-92.
6
5.8
5.6
5.4
5.2
5
4.8
log
Import liberalisation
RETAIL
WHOLESALE
1 23 45 67 89 111 133 155 177 199 221 243 265
12 34 56 78 100 122 144 166 188 210 232 254
auction number
auction rate
fitted trend


NIGERIA 1986-88.
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
log
COMPETITIVE
DUTCH
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65
3 7 11 15 19 23 27 31 35 39 43 47 51 55 59 63 67
auction number
auction rate
fitted trend

APPENDIX I: Econometric methodology.

The main objective of this research is generating an asymptotically efficient estimates for the equilibrium model of section 2. The existence of cointegration readily guaranteed consistent (in fact super-consistent) estimation for the equilibrium parameters from a simple OLS regression of equation (1) above (Engle and Granger (1987)). This important property has been the main reason behind the enormous popularity of cointegration regression in the past few years. As pointed by Phillips and Loreton (1991), however, the cointegration regression usually produces substantially inefficient asymptotic estimations. Given our interest in generating asymptotic point estimators with smaller margin of errors for the true equilibrium, the direct cointegration estimation will not be adequate for the problem at hand.

Fortunately, Phillips and Loretan (1991) propose a useful empirical paradigm based on statistical distribution theory that can be used to generate asymptotically efficient estimation in the context of single equation cointegration (or error-correction) econometrics. Phillips and Loretan show that asymptotic efficiency obtains in the case of cointegration regression only for the fully modified OLS (Phillips and Hansen (1990)--with semiparametric serial correlation and endogeneity corrections). And in the case of a modified non-linear single equation error-correction specification (with lagged equilibrium relations and both lags and leads of ΔF_t as regressors). In what follows we will discuss the modified ECM, since it will turn out to be a direct generalization of the ECM consistent long-run cointegration equilibrium.

Consider the following typical cointegrated systems: let $y_t = \begin{bmatrix} e_t \\ F_t \end{bmatrix}\begin{matrix} 1 \\ m \end{matrix}$ be an n-vector with an I(1) process and $\mu_t = \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \end{bmatrix}\begin{matrix} 1 \\ m \end{matrix}$ be an n-vector stationary time series, with $n = m+1$. Now the cointegration equilibrium can be represented by the following systems (Phillips and Loretan (1991), Phillips (1991)):

$$e_t = \beta' F_t + \mu_{1t} \tag{1'}$$

$$\Delta F_t = \mu_{2t} \tag{2'}$$

Assuming that $\mu_t = \sum_{j=0}^{\infty} A_j \epsilon_{t-j}$; $A_0 = I \sum_{j=0}^{\infty} j^{1/2} \| A_j \| < \infty$, where $\epsilon_t \sim \text{iid } N(O, \Sigma)$; Phillips and Loretan (1991) show that system (1') and (2') is equivalent to the following expression:

$$e_t = \beta' F_t + \sum_{j=1}^{\infty} d_{ij} (e_{t-j} - \beta' F_{t-j}) + \sum_{j=0}^{\infty} d_{2j}' \Delta F_{t-j} + \eta_t \qquad (3)^{42}$$

[42] Phillips and Loretan (1991) emphasize the point that asymptotic theory requires this particular nonlinear formulation of the ECM, as opposed to the other frequently used formulation in the literature based on using Δe_{t-j} instead of $(e_{t-j} - \beta F_{t-j})$. this is because lags of Δe_t are not in general an adequate proxy for the past history of μ_{1t}, because of the persistence in the effects of the innovations that arises from the presence of unit roots in the system.

where $\eta_t = \mu_{1t} - E(\mu_{1t}|X_{t-1})$ is a Martingale difference sequence with respect to the filtration $X_{t-1} = \sigma\{\Delta e_{t-1}, \Delta e_{t-2} \ldots, \Delta F_t, \Delta Ft-1, \ldots\}$. A suitably truncated version of (3) above has been employed in single equation error correction (SEECM) empirical work (e.g. Hendry and von Ungern-Sternberg (1981)).

Phillips and Loretan (1991), however, show that a truncated version of (3) will fail to produce asymptotically efficient estimators, because the truncation error is non-negligible due to shock persistence. Also Phillips (1988a) show that there is a general failure of valid conditioning--a desirable feature in the Hendry-Richard methology[43]--due to the presence of feedback from μ_{1t} to μ_{2t}. To rectify the failure of equation (3) to produce asymptotically efficient estimators of β, Phillips and Loretan (1991) show that this needs the elimination of this feedback, and they suggested including leads of ΔF_t in the regression of (3) so that in the limit μ_t is orthogonal to the entire history $(\Delta F_t)_{-\infty}^{\infty}$. Their revised version of (3), therefore, has the following form.

$$e_t = \beta' F_t + \sum_{j=1}^{\infty} d_{1j} (e_{t-j} - \beta' F_t - j) + \sum_{j=0}^{\infty} d_{2j}' \Delta F_{t-j} + \sum_{j=1}^{\infty} d_{3j}' \Delta F_{t+j} + v_t \tag{4}$$

where $v_t = \eta_t - \sum_{j=1}^{\infty} d_{3j} \mu_{2,t+j}$, and is a martingale difference sequence with respect to the filtration $\mu_{t-1} = \sigma(\mu_{1t-1}, \mu_{1t-2}, \ldots, (\mu_{2t})_{-\infty}^{\infty})$.

A truncation of (4) that will be estimated in this paper allows for two lags and one lead (Phillips and Loretan (1991)):[44]

$$\begin{aligned} e_t = {} & \beta' F_t + d_{11}(e_{t-1} - \beta' F_{t-1}) + d_{12}(e_{t-1} - \beta' F_{t-2}) \\ & + d_{20}' \Delta F_t + d21' \Delta F_{t-1} + d_{22}' \Delta F_{t-2} \\ & + d_{31}' \Delta F_{t+1} + v_t \end{aligned} \tag{5}$$

---

[43] The Hendry-Richard approach (see Gilbert, 1986) suggests that a successful single-equation ECM should meet the following criteria: (1) data coherency; (2) valid conditioning; (3) encompassing; (4) theory compatibility; (5) parsimonious orthogonal decision variables; (6) parameter constancy.

[44] The relative successful order (2, 1) truncated model simulated by Phillips and Loretan (1991), however, contains only two long-run parameters.

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